Measuring Luxation of Dental Implants In Vitro*

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Abstract

Loading of dental implants immediately after placement is an important attribute for the patients receiving the implants, but may induce a failure in the osseointegration of the implant. Even though the loading required to induce such failures is currently unknown, it is estimated that the osseointegration may fail if an implant is luxated in bone by more than 50 μm. Therefore, the ability to measure this loading can provide the practicing dentist with critical information in estimating the functional life of a newly placed implant.

This paper discusses the design and fabrication of a *cost-effective* test setup for measuring the amount of horizontal force required to displace a non-osseointegrated implant, and presents the results of our pilot in vitro load measurements for dental implants mounted in a bovine mandible. Although the sample size of our measurements is not statistically significant, the initial data shows that the amount of horizontal force required to displace a 4.3×13 mm implant by 50 μm is in the order of 150N, and therefore the implant may fail to osseointegrate for biting forces that are as low as 440 N, which is about half of the typical biting force of an adult in the molar area. One implication of our study is that implants having smaller diameters may move and fail to osseointegrate for even lower biting forces. Furthermore, our work represents the first steps in developing appropriate metrics to correlate the measured biting force generated by a patient with his or her candidacy for immediate functional implant loading.

1 Introduction

Edentulous dental patients are, naturally, quite disappointed when they find the long healing period required for osseointegration of a dental implant. There have been studies that examine the success of implants that are functionally loaded immediately after implantation [1], but researchers agree that maintaining implant immobility is ideal for proper osseointegration. However, in most cases complete immobility is not possible or practical. This raises several important questions, including:

- How much can a newly placed implant be loaded without compromising its osseointegration?
- How much does this loading change with time as the implant osseointegration progresses until full loading is possible?
- What constitutes an appropriate loading condition, and how do we measure these characteristics?

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Since there are many factors affecting these characteristics that have not yet been agreed upon or standardized in any way, the available literature provides mixed data. The current opinion is that if a healing implant undergoes a micromovement (displacement) larger than 50-150 microns, a microhemorrhage may occur, which induces subsequent fibrous growth that may cause failure in the osseointegration of the implant [2]. However, the range of biting forces that prevent osseointegration of newly placed implants is currently unknown [3].

The occlusal forces generated by the jaws are more powerful in the posterior (i.e., the molar area) than the anterior. Forces in the molar area are in the range of approximately 250-1250 Newtons (N), while the anterior forces are generally about a third of that [4, 5, 6]. During function, the jaws transmit the load to prostheses and the supporting implants. A healing implant that is not yet osseointegrated may be susceptible to luxation during chewing or parafunction [7, 8, 9]. Depending on a number of factors, including the jaw force generated by a patient, a newly installed implant may move in the bone and fail to osseointegrate. Thus the occlusal force exerted by a patient may luxate a newly placed single implant and displace it, which will induce a failure in the implant osseointegration [1, 2]. Clearly, splinting newly placed implants may increase the critical force needed to luxate the implants [10, 11], but the existing studies of splinting do not seem to be conclusive [12].

In this work we take the first steps in understanding the range of forces causing improper osseointegration by developing an inexpensive yet accurate test setup for measuring the amount of force required to displace a dental implant 50 microns, as measured at the surface of the bone. Our preliminary experiments measured the amount of horizontal force necessary to move a non-osseointegrated implant placed in a bovine mandible by 50 microns, which sets a basis for further studies. The ability to measure this loading accurately, for statistically significant samples of various bone morphologies, and in a cost effective manner can provide sufficient data to develop an extensive characterization of the implant loading. In turn, such a characterization can be correlated with the biting force delivered by individual patients that would provide critical information to the practicing dentist for estimating the functional life of a newly placed implant. Thus, the biting force generated by a patient may be measured to determine his or her candidacy for immediate functional implant loading.

2 Design of the Testing Device and the Test Setup

Clearly, there are many ways to apply a predefined amount of force to a dental implant, and to measure the displacement generated by such a loading. However, the two *competing* objectives of performing the test accurately while, at the same time, limiting the cost of the device raises some interesting challenges. The requirements that the design had to meet can be summarized as follows. The primary challenge was maintaining the accuracy of the implant measurement by holding the displacement of the device and of the bone to negligible values, so that their influence on the measured values would be minimal. The device had to be portable so that the calibration and measurements could be done at various locations, and had to accommodate sequential implant testing for implants placed at various heights relative to a datum reference. The bovine mandible in which the implant was mounted had a non-predictable shape and size, which required an adaptable securing mechanism. The range of forces that the device had to be capable of applying was from 0 to 2000N, and the expected displacements were limited to 200 microns. The total cost of building the measurement device was limited to be lower than that of an average laptop computer, which is

a fraction of the costs of other commercially available testing machines.

Several possible configurations of the measurement device were considered and evaluated according to their accuracy, simplicity and cost, but they are not discussed here due to space constraints. The final design of our device is schematically shown in Figure 1(a). The height of the push rod, which remains fixed during testing, can be adjusted to accommodate various bone thicknesses. The height and orientation of the implant mounting can also be adjusted relative to the table so that the angle of the applied force relative to the implant can be adjusted. The bone is mounted in the dental stone which is rigidly attached to the displacement sensor). This, in turn, minimizes the effects of the compliance of the device from the measured displacement, while offering adaptability for securing the bone and implant.

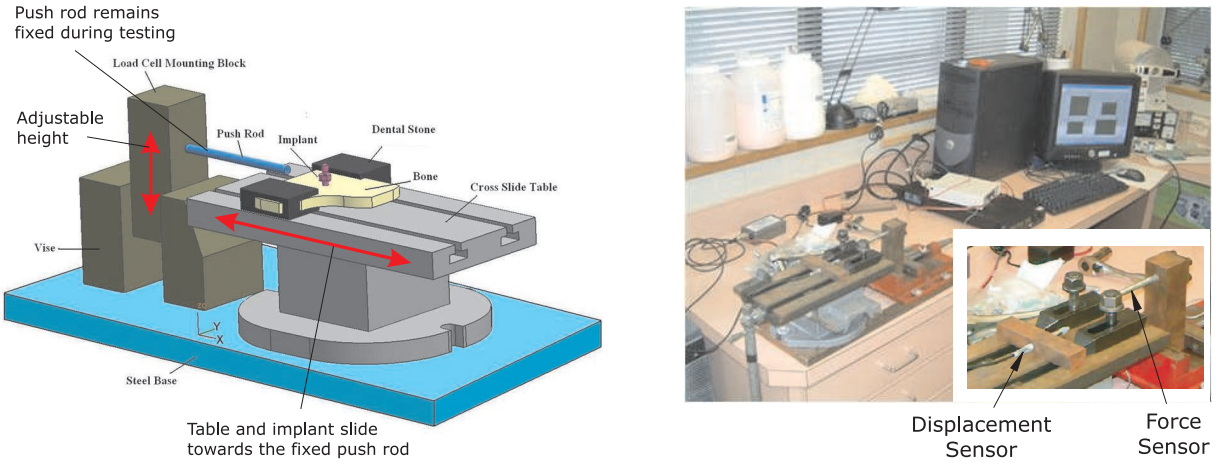


Figure 1: A schematic representation of the final design used for testing (a). The bone is mounted in the dental stone which is rigidly attached to the displacement sensor seen in Figure (b), which shows the final setup of the testing device for luxated implant measurements.

In such a testing scenario, the energy generated by the force applied to the implant mounted in the bone will be primarily absorbed by the bone, since the implant and the device itself are practically rigid compared to the rigidity of the bone. Consequently, this has several effects on the experiment. As the force is applied, and the implant starts to dislocate, the bone behind the implant is compressed and starts to deform both locally (local deformation near the implant-bone interface) and globally (bending of the bone). Thus, the final device had to mount the bone itself in such a way that the global bone deformation would remain negligible. In order to isolate the measurement of the implant dislocation (displacement), the measurement sensor and the force applicator were mounted on opposite sides of the implant as shown in Figure 1. Furthermore, the measurement sensors were placed as close to the implant as physically possible to eliminate any other deformations of the device from the measured data.

The bone was mounted in a rectangular Die-Keen hard dental stone, which is secured in a table vise to hold the bone securely for testing. The hard dental stone provides the most secure yet adaptable method of attachment for the bone, and, at the same time, increases the global rigidity of the mounted bone without affecting its local properties around the implant. Our table vise is

controlled by a lead screw allowing transversal movement of the bone relative to the point of force application. Consequently, this design allows several mounted implants to be tested sequentially without removing the bone from the vise. The final design secures the bone on a table moving relatively to a fixed rod that applied the force due to the relative motion between the moving table and the rod, and allows the control of the vertical position relative to the implant of both the force application and displacement measurement in order to support testing of various bone thicknesses. The force sensor is integrated into the support of the fixed rod, and the force is applied mechanically using controlled levers and weights via the lead screw, which provides consistent yet simple means to apply the implant loading. A force sensor (Omega LC302-500, with an accuracy of +/- 10N at 2200N, Omega Engineering Inc, Stamford CT) is used to measure the force applied to the implant, and a linear displacement sensor (Omega GP911-1-S, with an accuracy of +/- 2 microns, Omega Engineering Inc, Stamford CT) measures the displacement of the implant.

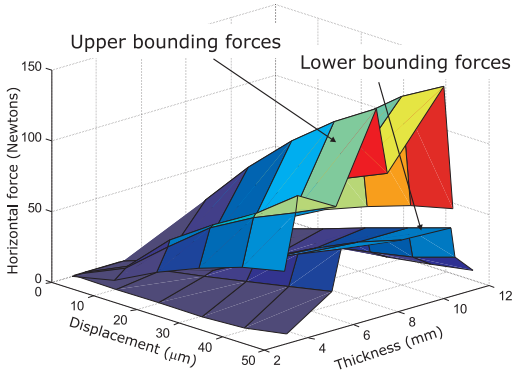
Our two sensors are connected via data acquisition cards to Labview, a commercial data acquisition software [13], to acquire, analyze and display in real time the measured forces and displacements. The sensors have been calibrated within the Labview environment against certified calibration weights and thickness gauges before testing was initiated.

For testing purposes, a fresh bovine mandible was secured from the University of Connecticut Pathobiology Department. A section of ramus was cut with a bone saw and stored at 3 degrees Celsius in humid conditions. At the time of testing, sections of the ramus were cut into strips for osteotomies and implant placement. After the dental stone used to secure the bone set for 45 minutes, a grinding wheel was used to shape the stone to fit into the table/vise. Osteotomies were drilled into the bone for the dental implants (CamLog, Henry Schein, Melville, N.Y.), which were implanted using the standard torque of 300Nmm. Each osteotomy/implant was given a letter designation. The bone thickness for each testing site was measured with a Boley gauge. The implants were then installed into the bone osteotomies. The 13 mm length implants used in this experiment had a diameter of 4.3mm. Once the implants were installed, the bone/stone was clamped to the cross-slide table. The lateral force was applied to the implants monotonically increasing until the deflection readings reached 150 microns. The data acquisition program saved the data, and the sensors were re-initialized. This procedure was repeated for the remaining implants.

3 Data Collection and Interpretation

Force-displacement curves were collected for each implant mounted in the bone. By post-processing the collected data, we identified the forces required to displace an implant in 10 micron increments up to 50 microns. This data was used to generate the 3D surfaces shown in Figure 2 that show how the measured horizontal force varied with the measured displacement and thickness of the bone. Observe that the force increases monotonically with the displacement, but varies significantly for different thicknesses of the bone as measured at the mounting location of each implant, which changed with each mounting. Our results suggest that these variations are due to the inhomogeneity of the bone properties across the bone thickness, which practically changes the (local) load carrying capacity of the bone.

Figure 2(a) shows the upper and lower bounding surfaces for the measured force. The interpretation of these bounding surfaces is as follows: for a given displacement of d microns and bone thickness of t mm, the lower bounding surface shows the value of the force up to which the displacement of the implant remains smaller than the prescribed value of d microns so that the



(a)

Bone Thickness (mm)	The Force (in Newtons) required to displace the implant (Upper Bound)				
	10 μm	20 μm	30 μm	40 μm	50 μm
2.9	7	22	35	45	52
3.4	13	38	61	78	91
3.5	14	42	63	80	103
5.2	11	32	55	73	87
7	45	78	106	129	148
7.5	32	54	72	87	100
10	45	81	109	133	150
10.4	16	32	44	54	62

Bone Thickness (mm)	The Force (in Newtons) required to displace the implant (Lower Bound)				
	10 μm	20 μm	30 μm	40 μm	50 μm
3	0	0	0	2	7
5	1	3	5	9	12
5.4	1	12	28	43	56
8.1	0	10	25	39	50
10.3	9	19	29	39	49
10.5	3	6	11	17	27
11.3	0	1	4	9	14

(b)

Figure 2: (a) The upper and lower bounding forces for the applied horizontal force; (b) Measured data used to generate the two bounding surfaces.

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osseointegration is not compromised. The upper bounding surface shows the value of the force above which the displacement of the implant exceeds the prescribed value of d microns, which implies that for horizontal forces greater or equal to this upper bound, the osseointegration will always be compromised. Finally, for horizontal forces that are smaller than the upper bounding surface, but larger than the lower bounding surface, the osseointegration may or may not be compromised, depending on the local load carrying capacity of the bone, which will in turn vary not only with the local geometry of the bone, but also with each individual patient. The numerical values corresponding to the upper and lower bounding surfaces are shown in Figure 2(b).

The variation in the magnitude of the biting force required to produce a horizontal force of 150 N (this is the largest measured force generating $50\mu m$ of the implant - see Figure 2(b)) as a function of the angle between the biting force and the vertical direction can be easily found by using straightforward trigonometry. Note that this value of the biting force greatly depends on the angle between the direction of the actual biting force and the vertical direction (which is hard to predict in general since it is a function of the tooth morphology, the individual's anatomy, and, last but not least, of what the patient is biting on). For example, a 1300N biting force produces a horizontal force of 150N (corresponding to our measurements for 4.3X13 implants) for an angle of approximately 6.6 degrees with the vertical which is fairly close to a vertical biting force.

Note that an implant that has a diameter smaller than 4.3mm (used in this study) has a smaller contact area with the bone than the 4.3mm diameter implant, and that the ratio between the two contact areas is proportional to the ratio of the two diameters. Therefore, such an implant will require an even smaller horizontal force than the 4.3mm diameter implant to undergo a displacement of 50 microns. Observe that the smaller the horizontal force, the smaller the maximum angle would be for the same value of the biting force. Consequently, our data suggests that if a patient that develops 1300 N of jaw force should *not* be considered for immediate function loading of newly placed dental implants, even in the anterior. Furthermore, our results indicate the existence of three distinct load zones for these horizontal forces (see Figure 2):

- a "safe" zone that contains the values of the horizontal forces producing displacements smaller

than the prescribed displacements of concern;
- a "prohibitive" zone containing force values that are high enough to provide large displacements that would compromise the osseointegration; and
- finally, a "risk" zone that contains all the forces that could produce displacements compromising the osseointegration.

4 Conclusions

Immediate loading of newly placed dental implants is a consideration to meet patient's demands. However, immediate loading may induce the implant's failure to osseointegrate, particularly since the patient biting force may reach 1300 N in the posterior jaws. It is suspected that if an implant is luxated in bone more than 50 microns, the osseointegration may fail, and that any forming bone will be replaced by fibrous tissue which inhibits the proper osseointegration.

This paper presented the design and fabrication of a test setup that can measure the horizontal force required to displace a newly placed implant by a prescribed distance at the microscale. We have shown that such a test setup can be not only accurate, but also cost effective and fairly simple to build. We used our testing device to complete a pilot study aimed at finding the amount of horizontal off-axial force required to move a non-osseointegrated implant 50 microns as measured at the surface of the bone. The initial data shows that the amount of horizontal force required to displace a 4.3X13 implant by 50 microns is in the order of 150 Newtons. Assuming that the angle between the direction of the biting force and the vertical is between 0 and 20 degrees, our data shows that a 4.3X13 implant may fail to osseointegrate for vertical biting forces that are as low as 440N.

Future studies should perform tests on more implants and bone samples, which will provide more data points, and hence a more complete characterization of these forces. For the thicker sections with soft cancellous bone in the center, it may be helpful to note the thickness of the cortical sections, along with the thickness of the cancellous section in the center. However, a comprehensive quantification of these three load zones would require the consideration of additional factors. Importantly, the resulting data could be extrapolated to correlate an individual patient's measured biting force to the ability to induce a 50 micron luxation and subsequent failure to osseointegrate. Thus, a patient may be measured to determine his or her candidacy for immediate functional implant loading.

References

[1] Szmukler-Moncler, S., Salama, H., Reingewirtz, Y., and Dubruille, J., 1998. "Timing of loading and effect of micromotion on bone-dental implant interface: review of experimental literature". *J Biomed Mater Research,* **2**(43), pp. 192–203.

[2] Brunski, J., 1999. "In vivo bone response to biomechanical loading at the bone/dental implant interface". *Adv Dent Res*(13), pp. 99–119.

[3] Isidor, F., 2006. "Influences of forces on peri-implant bone". *Clin Oral Imp Res,* **3**(17, supplement 2), pp. 8–18.

[4] Gibbs, C., Anusavice, K., Young, H., Jones, J., and Esquivel-Upshaw, J., 2002. "Maximum clenching force of patients with moderate loss of posterior tooth support: a pilot study". *J Prosth Dent,* **5**(88), Nov., pp. 498–502.

[5] Payne, A., and et al., 2001. "One-year prospective evaluation of the early loading of unsplinted conical branemark fixtures with mandibular overdentures immediately following surgery". *Clin Implant Dent Relat Res,* **1**(3), pp. 9–19.

[6] Richter, E., 1995. "In vivo vertical forces on implants". *Int J Oral Maxillofac Implants,* **1**(10), Jan-Feb, pp. 99–108.

[7] Wohrle, P. "Single-tooth replacement in the aesthetic zone with immediate provisionalization: fourteen consecutive case reports".

[8] Kupeyan, H., and May, K. "Implant and provisional crown placement: a one stage protocol". *Implant Dent.*

[9] Andersen, E., Haanaes, H., and Knutsen, B. "Immediate loading of single-tooth iti implants in the anterior maxilla: a prospective 5-year pilot study". *Clin Oral Implants Res.*

[10] Schnitman, P., Wohrle, P., Rubenstein, J., Silve, J., and Wang, N.-H. "Ten year results for branemark implants immediately loaded with fixed prostheses at implant placement". *Int J Oral Maxillofac Implants.*

[11] Gatti, C., Haefliger, W., and Chiapasco, M., 2000. "Implant-retained mandibular overdentures with immediate loading: a prospective study of iti implants". *Int J Oral Maxillofac Implants,* **3**(15), May-Jun, pp. 383–388.

[12] Gross, M., and Laufer, B., 1997. "Splinting osseointegrated implants and natural teeth in rehabilitation of partially edentulous patients. part i: laboratory and clinical studies". *J Oral Rehabil,* **11**(24), Nov, pp. 863–870.

[13] National Instruments, 2006. Labview. Austin TX.